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<u>Measurement of mobility of electrons in nanocrystalline Si using space charge limited currents</u>

Steady state electron conductivity mobility is an important parameter for increasing the performance of photovoltaic devices. A very low mobility could adversely impact the fill factor and current of the device, and change it from a hole-controlled into an electron-controlled device. The traditional way of measuring mobility is to use Hall effect or transient measurements. The former require that films be deposited on insulating substrates such as glass, and the latter give information about drift mobility, not conductivity mobility. Solar cells are steady state devices; what we need is conductivity mobility. Measurements made on glass substrates provide information about transverse mobility, whereas solar cells operate in the vertical direction, and we need a measurement of vertical mobility. Also, the films deposited on glass may not necessarily be identical to films used in devices which are deposited on conducting substrates such as steel or tin oxide.

In this report, we describe a simple technique that has been used to measure conductivity mobility in the vertical direction on nanocrystalline Si films deposited in device type structures. The technique consists of using space charge limited current (SCLC) in ss/n+nn+/Al type structures deposited on steel substrates. It will be recognized that the first two layers, n+ and n nanocrystalline Si:H on stainless steel , are identical to device type layer which are ss/n+np+. Thus, the measurements represent vertical mobility likely to be operational in solar cell devices.

The SCLC technique relies on the fact that once significant charge has been injected into the material, the current is no longer controlled by Ohms' law based on native carrier concentration N_d, but rather will be controlled by injected charge. The current density (J) expression is:

$$J= 1.12\ \varepsilon\mu\ V^2/L^3,$$

where V is the applied voltage, μ is the mobility, ε is the dielectric constant and L is the length of the n layer. Therefore, by plotting J vs. V^2, we can obtain an estimate for the value of mobility. Care should be taken to make sure that we are indeed measuring the true mobility, i.e. effects such as extraneous series resistances etc. should be eliminated. Also, one must make sure that the device moves from ohmic to square law behavior at the voltage that is necessary to ensure that SCLC conditions are met, namely that injected charge εEo > resident charge (qN_dL), using the value of N_d determined from a measurement of mobility and ohmic resistance.

In Fig. 1,we present the I vs. V data for a typical sample, which shows the expected transition from ohmic to non-ohmic behavior at higher voltages. The same curve is plotted as J vs. V^2 in Fig. 2, clearly showing a square law behavior. The value for mobility deduced from this data is

1.6 cm^2/V-sec. In Fig. 3, we show the mobility values measured on a series of nanocrystalline Si films, all made using hot wire techniques. Note the very large grain sizes that can be obtained (56 nm) under appropriate growth conditions in hot wire deposited nc Si films. [The work on making films with large grain sizes will be presented later this year at ICANS-21]. As expected, the mobility increases as the grain size increases.

Note that the mid-level traps do not play a major role in the determination of mobility. That is because all the samples measured had resident doping densities in the range of a few $10^{14}/cm^3$. This means that the Fermi level was ~0.3 eV below the conduction band edge, above the traps which are known to be between 0.35 and 0.5 eV below the conduction band. That means all the traps were filled during growth by the native donors, most likely oxygen (which is, of course, why they are so effective as recombination centers for holes).

Further experiments to understand the temperature dependence of mobility and to measure hole mobility in p+pp+ samples are under way. We will also measure mobilities in VHF deposited samples.

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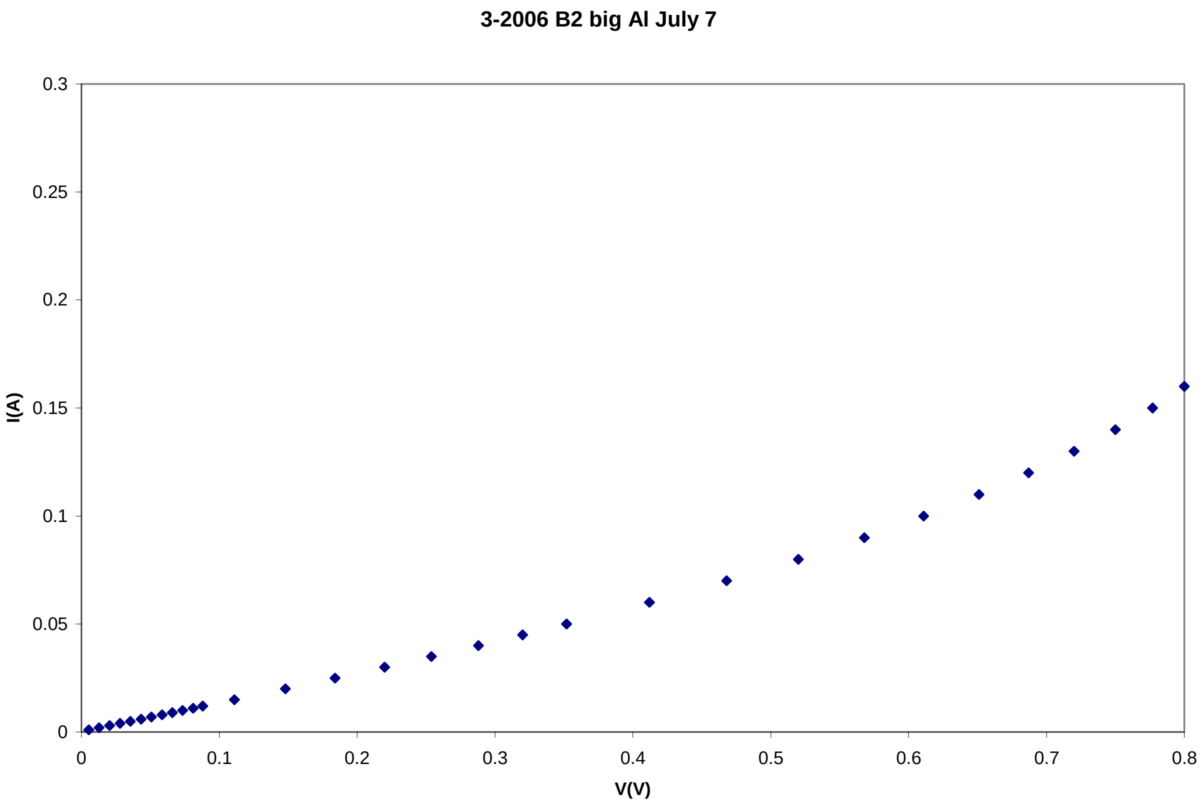

Fig. 1 I vs V curve showing a transition from ohmic to square law behavior

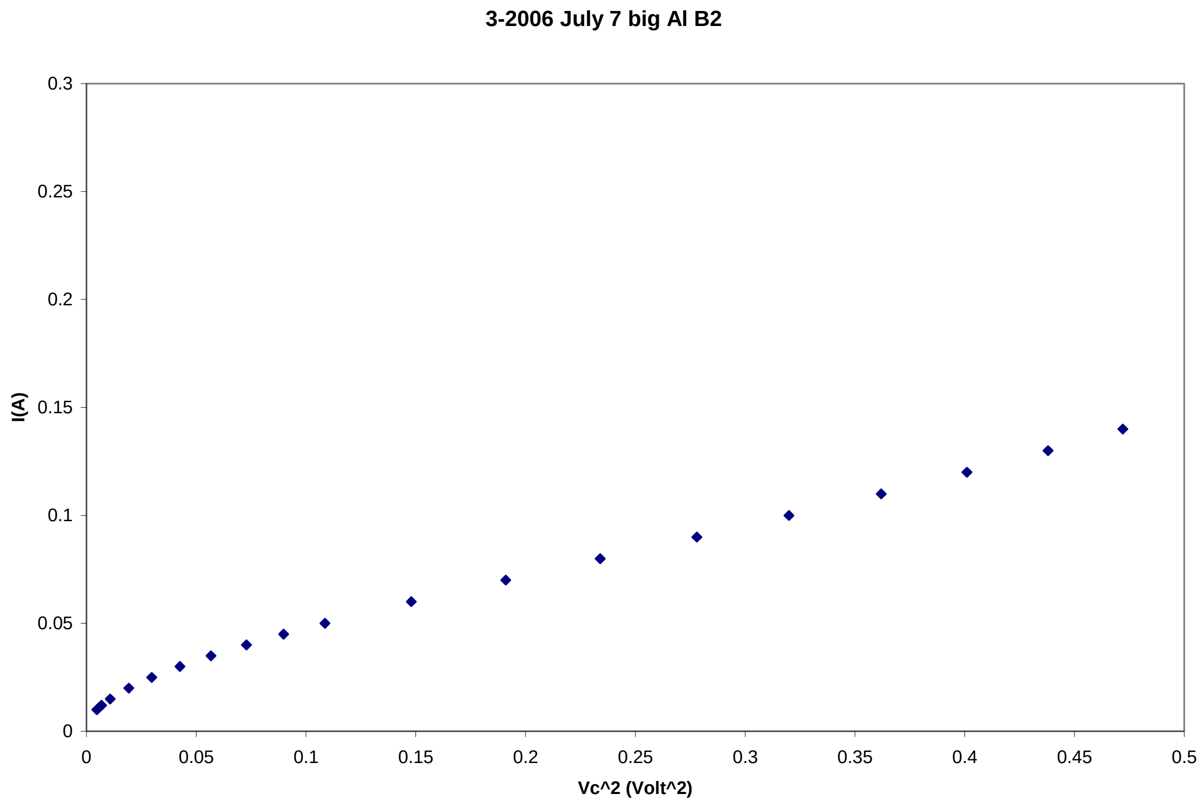

Fig. 2 I vs V^2 curve for the same device as in Fig. 1, showing linear behavior after the transition

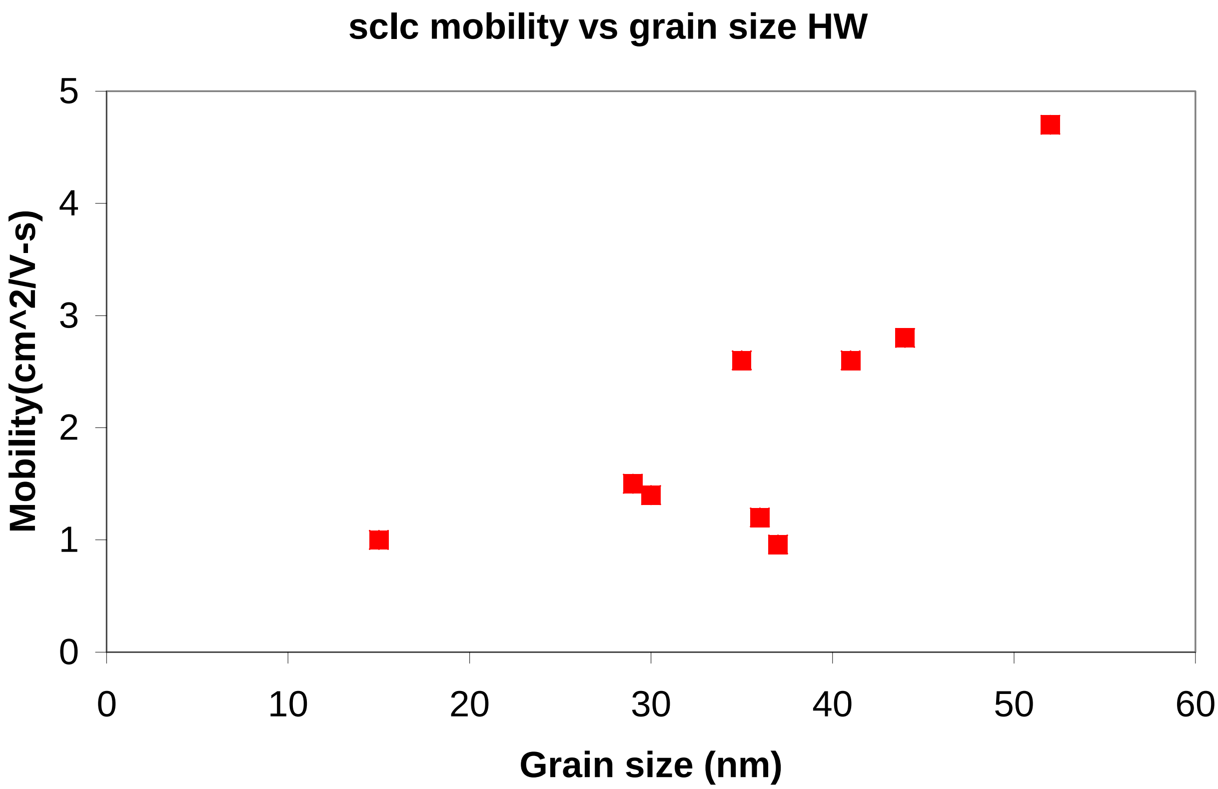

Fig. 3 Electron Mobility vs grain size in hot wire deposited nanocrystalline Si:H films